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CONSUMPTIVE USE OF WATER ON IRRIGATED LAND

By Wayne D. Criddle

IRRIGATION DIVISION

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AMERICAN SOCIETY OF CIVIL ENGINEERS

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PAPERS

CONSUMPTIVE USE OF WATER ON IRRIGATED LAND

By Wayne D. Criddle[1]

Synopsis

Generally not all irrigation water consumed in an area is used for crop production. Frequently great amounts of water can be recovered or saved. This paper gives a range in the amount of water consumed by varying types of vegetation under different climatic conditions in the United States. Alfalfa may consume 4.5 acre-ft of water per acre in the Salt River Valley of Arizona and only 1.5 acre-ft per acre in areas of Colorado. However, spring wheat, if it matures, will use about 1.25 to 1.50 acre-ft per acre regardless of where it is grown.

Introduction

Importance of Consumptive Use Information.—The importance of a knowledge of consumptive use of water is realized by all people living in the irrigated areas of the world. Just as it is important to know, before starting on a long trip across some of our sparsely settled West, whether the old car will give 10 or 20 miles per gal of gasoline, so it is important to know how much irrigation water will be required and consumed by the crops on an irrigated tract. Likewise, a knowledge of consumptive use of water is vital in arriving at an equitable division of the waters of a river system, particularly if interstate and international rights are involved.

After carefully estimating present and possible future consumptive use and stream-flow depletion, planning for future hydroelectric power plants and their power production becomes possible. Engineers and others working on water supply, drainage, flood control, and many other fields are finding it increasingly important to have a knowledge of the amount of water consumed by agricultural crops and other uses incidental to irrigated agriculture.

Note.—Written comments are invited for publication; the last discussion should be submitted by **May 1, 1952.**

[1] Senior Irrigation Engr., Div. of Irrigation and Water Conservation, Soil Conservation Service, U. S. Dept. of Agriculture, Boise, Idaho.

Although information on consumptive use is important in basin or large area studies, it is important too for the individual farm. In the design and layout of a farm irrigation system one of the first questions that must be answered is "How much water will be required by the crops and when must it be applied?" To answer this question satisfactorily requires a knowledge of the soil including water-intake rate, water-holding capacity, and other soil characteristics. It also requires a knowledge of the crops to be grown, the total seasonal water requirement of each crop and the peak daily, weekly, or sometimes peak monthly use of water. A knowledge of how much of the summer precipitation will be effective in satisfying the consumptive requirement is necessary, and a determination must be made of how much of the winter precipitation will be carried over as soil moisture and the contribution of ground water to consumptive use, if any.

Incidental Use of Irrigation Water.—In all irrigated areas, there is always a certain percentage of the water used within the area that is not actually consumed by the crops. Along with the crop use there is always some incidental use that cannot be economically avoided. This consumptive use that is incidental to irrigation varies widely between areas. It frequently offers an excellent opportunity for obtaining a better water supply for the crops or for expanding the irrigated acreage on the project. As the demand for water in a valley increases, the percentage consumed by agricultural crops usually becomes greater.

The total amount of water consumed by agricultural crops varies widely throughout the United States, but the consumption of irrigation water is considerably more variable. For some purposes a knowledge of the total amount of water consumed by the crops may be of prime importance. For other purposes an understanding of the amount of irrigation water required to satisfy the consumptive needs of the plants is considered most important.

Factors Affecting Agricultural Use

Consumptive use of water in an area is influenced by many factors including (1) climate; (2) cropping pattern; (3) available water supply; (4) soils and topography; (5) irrigation practices, and others.

1. *Climate.*—Undoubtedly climate is the factor having the greatest influence on the amount of water consumed by agricultural crops of an area. Investigators in the field generally agree that consumptive use of water will vary with temperature, length of growing season, precipitation, solar radiation, and humidity.

However, it is believed that the greatest effect of these factors is on the perennial crops, such as alfalfa and grass hay. The use of water by some annual crops, providing the crop matures, does not seem to be greatly affected by wide ranges of climate. As an example, the longest growing season and hottest temperatures found for any of the irrigated areas in Idaho is Lewiston, where the Snake River leaves the state. Here wheat is usually planted in late February or early March and harvested by mid-June. In contrast, spring wheat is usually not planted until late May on the Upper Snake River above Idaho Falls, Idaho, and is harvested the latter part of August or first

part of September. Consumption of water by the wheat crop appears to be about the same at the two places, even though the crop requires only the first half of the growing season to mature at Lewiston but nearly all of the growing season at the location above Idaho Falls. Of course double cropping might be practiced at Lewiston, and the total seasonal water requirement for each acre of land might be twice as great as on the Upper Snake River. Fig. 1 shows consumptive water requirements of wheat crops grown at Lewiston and above Idaho Falls.

With perennial crops water use and crop yields vary more directly with the temperature and length of growing season. Alfalfa may be expected to produce more hay in the Salt River Valley of Arizona than on the Upper Snake River in Idaho. With these greater seasonal yields will come a higher use of water.

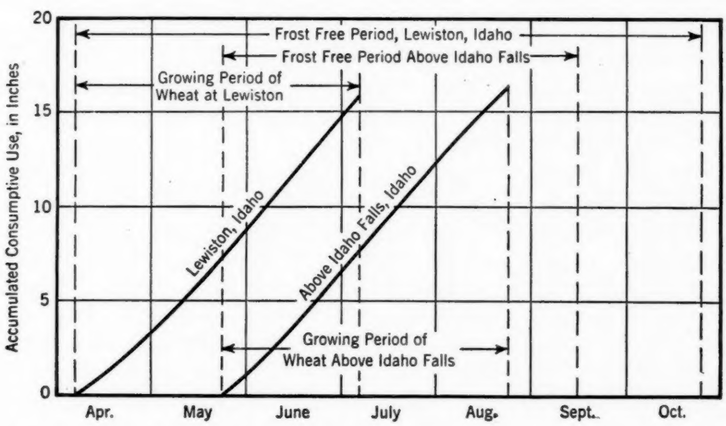

FIG. 1.—ACCUMULATED CONSUMPTIVE WATER REQUIREMENT OF WHEAT AT LOCATIONS IN IDAHO

2. *Cropping Pattern.*—Another important factor that must be considered with consumptive use of water is the cropping practice in the area. Crops such as alfalfa will generally use considerably more water each season than small grain crops. If an irrigated area has adequate water and is planted entirely to wheat, it may be expected to use less water consumptively than if planted entirely to alfalfa. However, the peak daily or weekly use for these crops may be quite similar.

3. *Available Water Supply.*—Probably the factor having the greatest influence on consumptive use, other than climate, is the water supply. Quantity, quality, cost, and availability are important considerations. Without an adequate supply, the consumption certainly will be less than when water is plentiful, all other factors remaining constant. With no irrigation water available, seasonal consumptive use cannot exceed the effective summer precipitation plus any carry-over of winter precipitation in the form of soil moisture.

Likewise, the quality of the water available may have an influence on the amount of water consumed. If the water is highly saline, good crop production

may require frequent heavy applications of water to maintain a downward movement of the salts and prevent a harmful concentration near the surface of the land. Under such practices evaporation from the wet or damp soil surface may materially increase the amount of water consumed inasmuch as consumptive use includes, by definition, the evaporation from the soil and water surfaces adjacent to the plants.

Cost may have a decided effect on the amount of water consumed by crops. Where water is cheap and plentiful, copious irrigations are frequently applied, causing high evaporation and incidental losses. As water becomes more expensive in relation to crop values and to other costs, it is usually applied more efficiently; sometimes less than the amount necessary for optimum crop production is applied.

Availability of water as needed has some effect on consumptive use but may be most important in increasing irrigation efficiencies. Those farmers receiving irrigation water from reservoirs having adequate storage capacity are much less likely to over-use water during the early part of the irrigation season than are their neighbors, whose only source of water is from an unregulated stream that runs high during the spring freshet but practically dries up during the latter part of the summer.

4. *Soils and Topography.*—Soils and topography play an important role in determining the amount of water consumed. Areas in which the fertility level is high give heavy yields, but water consumption, particularly for perennial crops, is greater. Texture, structure, depth of top soil, and other soil characteristics affect the use of water, especially the consumptive irrigation requirement. The amount of precipitation that the ground will absorb and make available for consumptive use of the plants varies widely with the soils and topography.

5. *Irrigation Practices.*—Consumptive use of water is affected by the way a farmer lays out his farm irrigation system and manages the available water. The wise irrigator will apply water when and as needed to keep the crop growing at or near a maximum rate. Such practices will tend to give high crop yields with a relatively great use of water per unit area. However, bad practices may also result in fairly great use of water because of the resulting incidental uses. If the land was not properly prepared for irrigation, ponding and drowning out of crops may result in some areas. Evaporation from such areas is great, and consumption of water in the area may be similarly high.

Consumptive Use Incidental to Irrigated Agriculture

Factors Responsible For Consumptive Use Variations.—As has been already stated, water is consumed in most irrigated areas that are not directly necessary for the production of agricultural crops. This use includes evaporation from free water surfaces and seeped lands and the transpiration of the natural vegetation that is inevitable when water is available. In areas, such as those along the Pecos River above Lake McMillan in New Mexico or the Gila River above Safford, Ariz., these incidental uses become extremely important. In each of these areas vast acreages of salt cedars consume great quantities of water. In other areas, willows, cattails, and sedges consume water. A por-

tion of this water will undoubtedly be salvaged and used beneficially for agricultural production when the need for water requires action.

The amount of water consumed by natural vegetation varies widely from one irrigation project to the next because of many factors. The length, slope, and shape of irrigation canals and ditches and the soils through which they pass have great effect on the amount of water lost in transit and consumed by natural vegetation. If the canals and ditches are lined and the amount of seepage is controlled, areas in which seepage appears and large patches of plants that consume great quantities of water will not develop. However, if the canals are unlined and traverse areas of flat, highly permeable soils, there are apt to be great quantities of water escaping from the canal. Unless the underdrainage is good and the seepage water escapes underground from the project, wet areas will develop. Soon natural water-loving vegetation will start growing. This growth, together with evaporation from any existing water surface and from the moist soil surface, can account for great water use.

Adaptability of Natural Vegetation.—The amount of water consumed by natural vegetation is somewhat dependent upon the type of vegetation that will grow in the area under natural conditions. In general, the larger the vegetation, the greater the amount of water that will be consumed. Usually tall cottonwoods or other trees will have a dense undergrowth of smaller plants, such as willows and grass. However, some types of vegetation grow better under some climatic conditions than they do under others. For instance, salt cedars or tamarisk, commonly found in many of our southwestern areas, do not grow and thrive naturally under northern or more rigid temperature conditions. In its natural habitat, tamarisk appears to be an important user of water. Further north and in the higher elevations willows replace the salt cedar, but the willows are likewise great users of water, although they may not have as high a peak use rate as the tamarisk.

In high mountain meadow country, such as on the headwaters of the Colorado River, large areas of dense willows are found. In fact, many ranchers must exert a continual effort to keep the willows out of the pasture or wild hay lands. Such vegetation begins using water early in the spring and continues to use water, if available, until late in the fall.

Likewise, sacaton, a plant that loves a high ground-water table, grows rank and dense under southwestern conditions, but will not live in the northern areas.

Frequently, on irrigated farms low spots are found in or at the and of the fields into which large amounts of surface waste water and silt collect. Such conditions are conducive to high farm consumptive use and give a particularly high use if based only on irrigated cropped lands.

High ground water, whether natural or caused by leaks from canals or irrigation applications, is conducive to great use of water. Many plants, including alfalfa, use much more water if it is readily available. To this greater use by the plants themselves must be added the increase in evaporation from the land and water surfaces.

Variability of Use Throughout the West

Regional Variations in Consumptive Use.—It is quite generally understood that the consumptive requirement of water varies throughout the West. The greatest use is, of course, in those areas having the longest growing seasons, highest temperatures, and lowest humidity. Some of the valleys in the United States where consumptive use is greatest are the Salt River and Yuma areas in Arizona, and the Central and Imperial Valleys of California.

Mimimum use is found in the higher, cool valleys. In high mountain valleys where frost may occur every month of the year, only a light crop of wild hay may be harvested some years. Under such climatic conditions little consumptive use occurs each season because of the short period during which crop growth takes place. The New Fork area above Pinedale, Wyo., is typical of such an area.

Use may vary widely because of the difference in crops grown in the various areas. There are a number of small valleys in southern California where one would expect a rather great use of water. Based on temperature and growing season records, the use in these valleys might be quite similar to that in the Imperial or Coachella Valleys of California. However, because of lack of adequate water for irrigation, only relatively low yielding grain or beans is normally grown. Furthermore, after the grain crop is planted, there is an attempt made to utilize all the precipitation possible, both winter and early spring. Precipitation alone will not produce a crop in these valleys, so one or two small applications of water may be made.

Such practices result in an extremely low average consumptive use when compared to that in an area such as the Mojave River area near Victorville, Calif., where climatic conditions are not too much different but where a major irrigated acreage is planted with high producing alfalfa. Table 1 gives some examples showing the variation in use between different areas:

TABLE 1.—Result of Studies on Consumptive Use of Water by Alfalfa and Small Gains

Location	State	Consumptive Use of Water by Crops, in Inches	
		Alfalfa	Small gains
Bonners Ferry	Idaho	24.0	17.5
Logan	Utah	25.0	17.5
Prosser	Washington	36.0	18.0
Mesa	Arizona	52.5	...

Consumptive Irrigation Requirement.—Rather frequently it becomes necessary to know the total amount of water consumed by a crop and also the net amount that must be supplied by means of irrigation and other sources. In areas in which ground water does not contribute to the requirement the only other sources of water are summer precipitation and soil moisture carry-over from the winter precipitation. Determining the proportional contribution from each source is extremely difficult since it varies widely from place to place. One of the most controversial points in any consumptive-use-of-water study is determining these contributions.

In the hotter climates, such as the Salt River Valley in which total annual precipitation is small, and a major portion of this occurs in storms of less than 0.5 in., there is always a question as to whether any of the precipitation is really effective. Under these Arizona conditions a characteristic summer storm develops rapidly. Rainfall occurs at a rather high intensity for a short duration, and then the storm clouds pass. The high rate of fall is frequently accompanied by heavy surface runoff from the fields. Precipitation that remains after surface runoff is soon evaporated from the wet foliage and ground surface without any significant quantity penetrating into the root zone of the crop. Under such conditions, the consumptive irrigation requirement is probably reduced little, if at all, because of the summer storm. However, in such areas, the total amount of precipitation that falls during the summer is relatively small in comparison with the total requirement. Therefore, whether this precipitation is considered as being effective or not may make little difference to the total irrigation requirement.

Under conditions found in the northwestern United States a rain storm, regardless of its size, is frequently accompanied by cloudiness and cooler weather that may last for several days. This lowering of temperatures and increased humidity may reduce consumptive use so that a large part of the precipitation might be considered effective. Also, in this area it is characteristic for the rain to fall more gently and over a longer period of time. This allows greater time for the precipitation to percolate into the root zone of the crops and become effective in reducing the consumptive irrigation requirement. This is particularly true under coastal conditions in Washington and Oregon and in northern Idaho. In the more arid portions of the Northwest, precipitation that normally falls during the growing season may be so small that it is practically insignificant in relation to the annual consumptive use.

East of the 100th meridian normal rainfall more nearly satisfies the water requirements of the crop. In fact, irrigation in the Middlewest and East has been considered practical on only a few high-priced truck crops. With the development of cheaper and more dependable portable sprinkler equipment, farmers in many areas of the East are finding it economically sound to provide for one or more irrigations each season to keep their crops growing at a maximum rate throughout the season. This supplemental irrigation may not be necessary each year, but, at least during the drier years, it may mean the difference between good yields or seriously reduced yields.

In order to understand the quantity of irrigation water that must be applied and when it should be applied, the amount and distribution of the effective precipitation should be known. Applying water in excess of crop needs is certainly not economical and may be harmful. By far the most economical way is to supply through natural processes the moisture needed by the crop. However, it is sometimes necessary to help nature supply water for plant requirements just as New York City finds it necessary to seed the clouds with dry ice or silver iodide in hopes of increasing its water supply.

The use of irrigation water to supplement rainfall is believed to be more clearly presented by chart, as in Fig. 2. This figure shows the cumulative

consumptive use and cumulative precipitation during the growing season at four locations having widely different climatic conditions.

The chart for Phoenix, Ariz., shows a possible total use for alfalfa of approximately 56 in. during the average frost-free period from February 10 to December 3. Normally, less than 6 in. of precipitation occurs during this period. Whether all of this precipitation is considered effective or whether it is disregarded entirely will not make a significant difference in the irrigation water requirement. Probably 75 to 80 in. of water would normally be applied to the field to provide the 56 in. required for consumptive use.

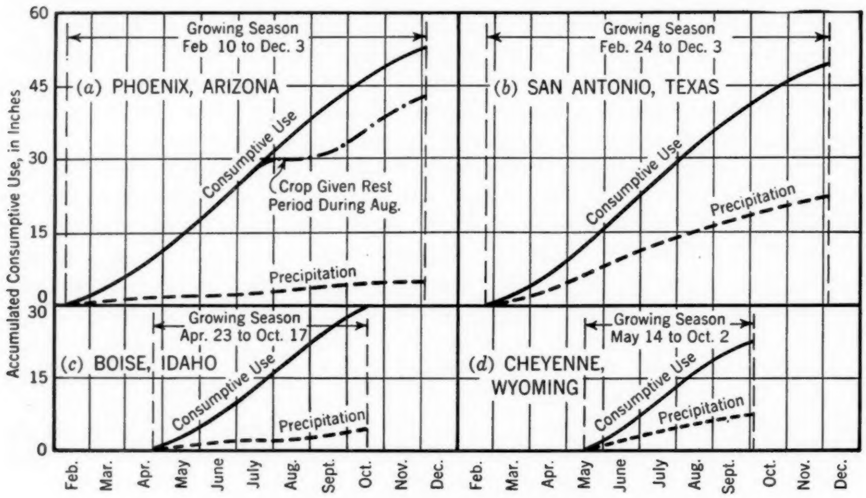

Fig. 2.—Potential Consumptive Water Requirement of Alfalfa

When the chart for San Antonio, Tex., with a similar frost-free period is studied, it can be seen that if precipitation is neglected it would make a considerable difference in the irrigation requirement. Here the growing season precipitation amounts to about 23 in., or nearly half the total possible requirement of alfalfa at that location.

At Boise, with a much shorter growing season, the summer precipitation amounts to only 4 in., and the consumptive use of alfalfa is believed to be about 30 in. Here, as at Phoenix, neglecting the summer precipitation will not make too much difference in the irrigation water requirement.

At Cheyenne, Wyo., with only a short growing season, the summer precipitation of 8 in. is a good proportion of the 23 in. that is the estimated consumptive requirement of alfalfa at this location.

Peak Use of Water by Crops

If the combined weight of all vehicles passing a point on a highway during a month were determined and this total divided by the number of vehicles, the average weight of each vehicle would result. However, if an engineer were to design a new bridge (using this average weight as the live loading), the

engineer would be looking for a new job as soon as the first oil tanker attempted to cross this bridge.

So it is with the design of an irrigation system. The system, particularly if it is of the sprinkler type, must be designed to handle the peak water requirement of the crop. The frequency of irrigation that must be designed will depend on the length of time the water added to the soil and stored for plant use will last when consumptive use is at a maximum rate.

Frequently peak use for a project as a whole has been determined from records of past water demands on some similar operating project. This method works well where all of the factors affecting water requirement, including cropping pattern, are similar. Another method that has been used occasionally is to estimate the average monthly irrigation water requirements of each crop[2] at the location under study, choose the peak monthly use, and divide by the number of days in the month. This average daily rate for the peak month is then multiplied by a factor which may be as large as 1.5.

To illustrate this method, assume that a design for a sprinkler system for an alfalfa field having light shallow soils near Grand Junction, Colo., is desired. The normal seasonal consumptive use is estimated to be 32.4 in.[3] Maximum use normally occurs during the month of July and is estimated to be 6.78 in. However, normal July precipitation is 0.75 in., leaving a deficit of 6.03 in. that must be supplied by some other means. The sprinkler system, therefore, would be designed to supply 1.5×6.03, or about 9 in. of water for consumption of the crop plus various losses. Assuming an irrigation efficiency of 75%, the sprinkler system must be designed to convey 12 acre-in. of water per acre if optimum crop-growing conditions are to be maintained during the extremely hot dry periods. Daily peak consumptive use rates being used by technicians of the Pacific Coast Region of the Soil Conservation Service for three broad climatic zones of the western states for the more common crops are given in Table 2.

TABLE 2.—VALUES OF PEAK DAILY USE OF SOIL MOISTURE FOR COMMON IRRIGATED CROPS PRODUCING OPTIMUM YIELDS

Crop	Use of Water in Inches Depth per Day		
	Cool climate	Moderate climate	Hot climate
Alfalfa	0.15	0.20	0.25–0.30
Pasture	0.12	0.16	0.20–0.25
Small grains	0.15	0.20	0.22
Potatoes	0.10	0.12	0.14
Sugar beets	0.12	0.15	0.20
Deciduous orchard	0.15	0.20	0.25
Orchard with cover crop	0.20	0.25	0.30

SUMMARY

In general, consumptive use of water in irrigated areas might be broken into two categories:

a. Consumption by agricultural crops; and
b. Consumption or use incidental to irrigation.

[2] "Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data," by Harry F. Blaney and Wayne D. Criddle, Div. of Irrigation and Water Conservation, Soil Conservation Service, U. S. Dept. of Agriculture, Washington, D. C., September, 1949.

[3] "Consumptive Use of Water in the Irrigated Areas of the Upper Colorado River Basin," by Harry F. Blaney and Wayne D. Criddle, Div. of Irrigation and Water Conservation, Soil Conservation Service, U. S. Dept. of Agriculture, Washington, D. C., April, 1949.

The amount of water consumed by agricultural crops is affected by many factors, of which climate is probably most important. Other influencing factors are soils, topography, water supply, irrigation practices, and the crops grown. The total depth of irrigation water required for consumptive use during the growing season is dependent on the effective precipitation that falls during the summer and the carry-over soil moisture from winter precipitation.

Perennial crops show wide variations in use of water at different locations of the West. Nearly $4\frac{1}{2}$ ft of water per yr is normally used by alfalfa in the Phoenix and Yuma areas of Arizona. A minimum use where alfalfa is grown successfully occurs in the higher northern valleys and is probably about $1\frac{1}{2}$ ft of water per year. Annual crops usually do not show such a wide variation in use. Approximately 15 to 18 in. of water will be used consumptively in producing a good irrigated wheat crop regardless of where it is grown.

Water consumed by natural vegetation incidental to irrigation may vary widely. Probably the greatest factor influencing the proportion of an irrigation supply thus consumed is the relative cost of the water in relation to other farm costs and to the value of the crops produced. However, there are other factors involved that also affect this proportion.

In many arid valleys, potentially short of water for agricultural purpose, reduction in the amount of water used by nonagricultural plants may present the greatest opportunity for expanding the agriculture or improving present supplies. Canal linings, better irrigation practices, better land leveling for irrigation, and other irrigation improvements might be used to salvage water. Consumptive use of water by crops cannot be decreased without decreasing yields, and it even appears that because of increasing yields the consumption of water per acre might also be increasing. The efficiency with which we convey and apply irrigation water thus offers our greatest opportunity for saving water.

Farm and field irrigation systems should be designed with capacity for supplying sufficient water to the crops during periods of unusually high demand. For some conditions a capacity of $1\frac{1}{2}$ times the irrigation requirement during the normal peak month has been considered desirable. However a factor smaller than $1\frac{1}{2}$ may be entirely satisfactory in areas of deep soils with high water-holding capacities.